VARIABILITY OF THE AIR TEMPERATURE FIELD IN THE ARCTIC

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Abstract: The arctic temperature field can be presumed to be one of the most sensitive indicators of climatic changes. In the present work an optimum interpolation technique is applied to the data network in the circumference of the Arctic Ocean and the surface air temperature field in the Arctic is analyzed. The results are compared with the analysis by WALSH (Mon. Weather Rev., **105**, 1527, 1977) who utilized the drifting ice station data. Both analyses agree fairly well, although some underestimations by the present work are noticed. Some preliminary examinations also are made to see whether the time change of the arctic temperature field would definitely be related to increase of the atmospheric CO_2 or to changes of other climate-controlling factors.

1. Introduction

Climatological significance of the air temperature in the Arctic has been noticed for several reasons: Secular changes of the surface air temperature in the high latitudes are considerably larger than those in the lower latitudes (ORVIG, 1970; YAMAMOTO and HOSHIAI, 1980), and the arctic temperature field can probably be presumed to be one of the most sensitive indicators of climatic changes. The ice- and snow-coverage may play an important role in the energy budget of the Arctic, and the variation may possibly cause a fundamental climatic change (*e.g.*, BUDYKO, 1972). The Arctic is considered to be remarkably sensitive to changes of climate-controlling factors such as the solar constant and atmospheric CO_2 concentration, according to the result of numerical experiments (*e.g.*, MANABE and STOUFFER, 1980).

Reliable estimation of the temperature field in the Arctic is obviously more difficult than that over the land areas in the lower latitudes, because of deficiency of long-term routine meteorological observations. Even if the arctic temperature field could be estimated with some method of spatial interpolation or extrapolation, it is not sufficient until we confirm the reliability of the results for further discussions. In the present work, we attempt to estimate the arctic temperature field, applying an objective analysis method which can give an estimate of error to the observational data network in the circumference of the Arctic.

It should not be overlooked that the climatic noise in time averaged values must obscure the signals caused by change of climate-controlling factors (LEITH, 1973).

The estimation by YAMAMOTO *et al.* (1981) indicates that the noise of the annual mean surface air temperature at a single station is about 1°C and that averaged over the latitude belt of 90°N–60°N is about 0.25°C. This implies that a meaningful discussion can be made much more easily on the change of spatially averaged climate than that of a local climate. In the present paper, some preliminary results on the variability of the temperature fields averaged over 90°N–60°N are presented, together with some discussions.

2. Data and Analysis Method

Because the data and the analysis method utilized in the present work were described elsewhere (YAMAMOTO and HOSHIAI, 1979), only the outline is given here. The monthly mean surface air temperature data at 178 stations north of 55°N, from January 1951 to December 1977, are taken from World Weather Records (U.S. WEATHER BUREAU, 1965–1967), Monthly Climatic Data for the World (NOAA, 1961–1977) and Air Temperature for the World (JMA, 1975). At each station, monthly mean temperature deviations from the 25 year mean (1951–1975) of the month concerned are computed for each 324 months. These monthly deviations data at unevenly distributed stations are analyzed for each month using the optimum interpolation technique mentioned just below. We may expect that the influence due to difference of station altitude is reasonably diminished in analysis of the deviations.

To an arbitrary grid point, the optimum interpolation technique gives a value of temperature deviation T_g' from the time mean $\overline{T}_g$ by a linear combination of the observed deviation data $\hat{T}_i'$ ($i=1, 2, 3 \ldots, n$) at n stations located within the range of appreciable correlation for the grid point concerned:

$$T_g' = \sum_{i=1}^{n} \hat{T}_i' P_i + I_g , \tag{1}$$

where overbar signifies time averaging, P_i the weighting factor and I_g the interpolation error, respectively.

The observed deviation $\hat{T}_i'$ consists of the true value T_i' and the observational error ϵ_i, the latter including the effects of local irregularities. $\overline{\epsilon_i^2}$ and $\overline{T_i'^2}$ are assumed to be homogeneous within the correlated range and are denoted by ϵ^2 and σ^2, respectively. The value of observational error ϵ can be easily estimated as about 1°C with the aid of structure function on the assumption that ϵ_i is random and independent of T_i'. Under the condition of minimizing $\overline{I_g^2}$, the following equations for determining P_i are derived:

$$\sum_{j=1}^{n} \mu_j^i P_j + \lambda^2 P_i = \mu_g^i \quad (i=1, 2, 3, \ldots, n) , \tag{2}$$

where $\lambda^2=\epsilon^2/\sigma^2$, and μ_j^i and μ_g^i are the correlation coefficients between the i-th and j-th stations, and between the i-th station and the grid point concerned, respectively. Then, the value of $\overline{I_g^2}$ is reduced to E_g^2:

$$E_g^2=\sigma^2(1.0-\sum_{i=1}^{n} P_i\mu_g^i)\,. \tag{3}$$

The detailed description of derivation of these equations can be found in GANDIN (1963), and YAMAMOTO and HOSHIAI (1979, 1980).

In practical use of this interpolation technique, it is prerequisite to see the dependency of correlation function and structure function upon the distance between a pair of stations. The spatial correlation coefficient, which varies somewhat with region and season, has a value of 0.5 at a distance separation of about 1000 km.

By using the interpolation technique, the temperature deviation and the interpolation error are estimated at the intersections of 10° latitude and 30° longitude (45° longitude only at 80°N) from 60°N to 80°N. The data at stations used for interpolation of one grid-point value are not used for another grid-point value. This limitation of data usage keeps the interpolation error in one grid-point value independent of another, and simplifies computation of error estimate in spatial average. The interpolation error of grid-point value significantly varies with season, geographical position and sparseness of the data network. The error of the monthly mean temperature for grid point at 60°N falls in the range of 0.6–5.8°C.

3. Variability of Spatially Averaged Temperature

Spatially averaged deviation of temperature and its error can be easily estimated, if the averaging is performed through numerical integration of grid point values located regularly. Under the condition that the errors of each grid point value are independent of each other, the error in zonal mean temperature is given by

$$\sqrt{\sum_{g=1}^{G} E_g^2}\Big/G \tag{4}$$

where G is the number of grid points used for zonally averaging. Latitudinal integration of the zonal mean gives the average over a latitudinal belt, in which case the error becomes generally smaller than that of the zonal mean. In a similar way, time averaging diminishes the error.

The 12-month running mean of zonal averaged temperature deviation along 70°N is given in Fig. 1. The 68% confidence limit of the error in this zonal mean value is about 0.2°C and shown with shading in Fig. 1. Figure 2 shows the 24-month running mean of the temperature averaged over 90°N–60°N, with error of about 0.09°C. Incorporating the temperature data at drifting ice stations with those of land stations, WALSH (1977) has performed a similar analysis. His results may be possibly the most reliable ones because of data abundance, although the period of

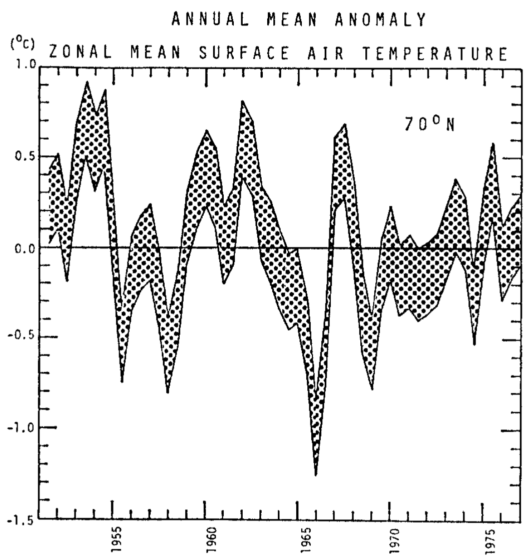


Fig. 1. The annual mean of the zonal mean temperature anomaly of 70°N. The 68% confidence interval of error in spatial averaging is indicated with shading.

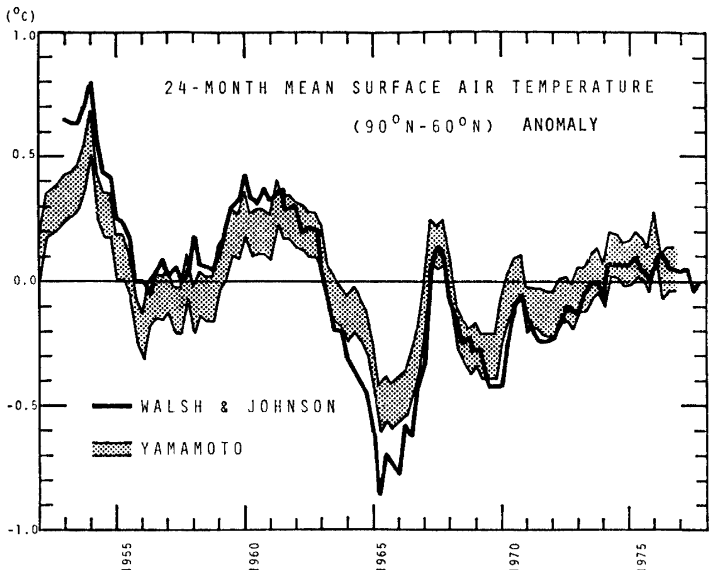


Fig. 2. The 24-month running mean of surface air temperature anomaly averaged over the Arctic north of 60°N. The 68% confidence interval of error in spatial averaging is indicated with shading. For comparison, the estimation by WALSH and JOHNSON (1978) is shown with a thick line.

his analysis is too short to be used for study of climatic changes. It is meaningful to examine how much reliable the analysis of the present work would be by referring to Walsh's work. One of Walsh's results is reproduced from WALSH and JOHNSON (1978) and shown in Fig. 2 with a thick line. It is noticed that the temperature changes estimated in the present work are smaller than those by WALSH (1977), although both estimates show a close parallelism with each other. The underestimation by the present work is obviously seen in a scattergram (Fig. 3), even if the error in spatial averaging is taken into account.

LEITH (1973) indicates an inherent noise appearing in averaging over a finite time interval. The 24-month running mean of the temperature averaged over the arctic region north of 60°N has a noise of about 0.18°C (YAMAMOTO *et al.*, 1981), and the range of noise is shown with broken lines in Fig. 3. Taking account of these noise and error, we have a satisfactory agreement between the results by WALSH and JOHNSON (1978) and those of the present work without using the data at drifting ice stations. However, there appears an obvious tendency of underestimation in the present work. It is promising that this underestimation should be improved by normalization of the weighting factor P_i in optimum interpolation (GANDIN, 1963). This improvement will be attempted in the near future.

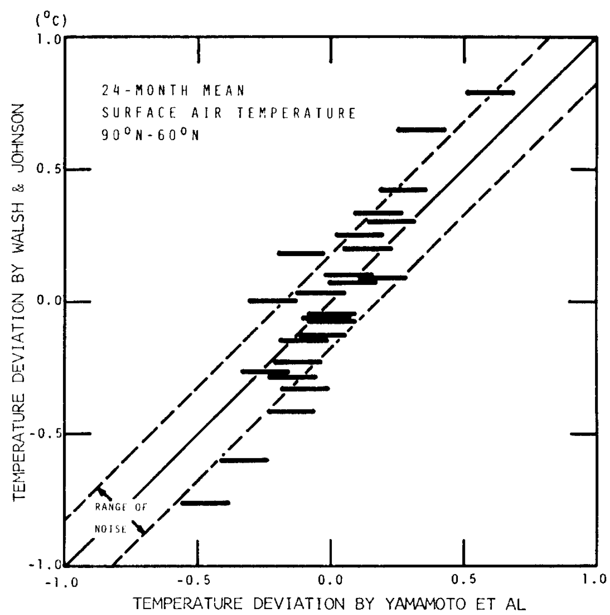


Fig. 3. Scattergram of the estimates by the present work and WALSH and JOHNSON (1978) of the 24-month mean of the surface air temperature anomaly averaged over the arctic region north of 60°N. The bars indicate the 68% confidence interval of error in spatial averaging of the present work.

4. Discussions

It is shown in the previous section that the temperature field estimated in the present work has some reliability in spite of much sparse data network. It is interesting to examine relationship between time-change of the temperature field and that of the climate-controlling factors. The first problem to be taken up is an examination of feedback processes of the temperature field and the extent of snow- and ice-coverage. In Fig. 4, the 12-month running mean of the extent of snow- and ice-coverage over the Northern Hemisphere derived from meteorological satellite observa-

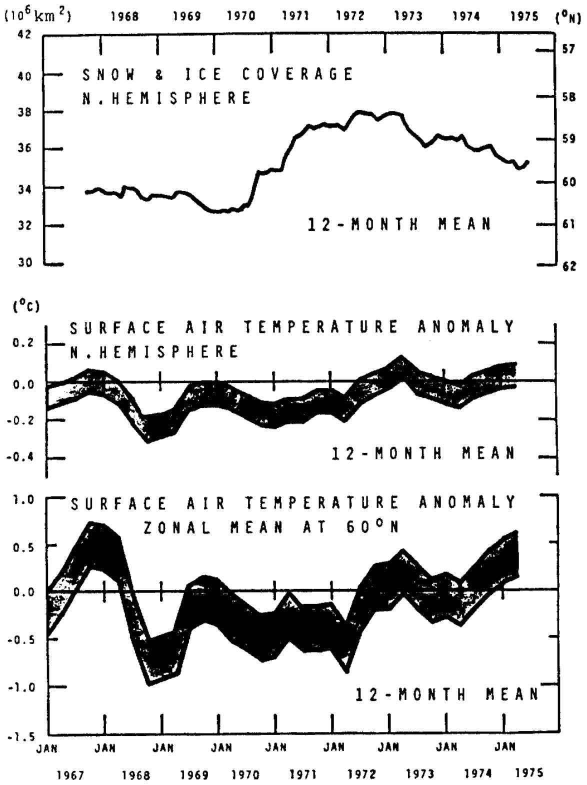
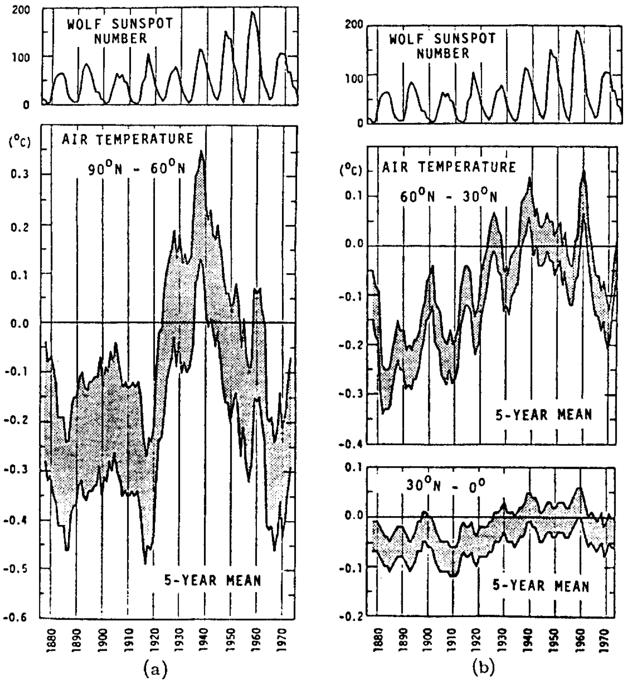


Fig. 4. The 12-month running mean of snow and ice coverage extent over the Northern Hemisphere by KUKLA *and* GAVIN *(1977) (upper panel). The 12-month running mean of the surface air temperature anomaly averaged over the Northern Hemisphere (middle panel) and averaged zonally at 60°N (lower panel). The 68% confidence interval of error in spatial averaging is shown with shading.*

tions, for the last 9 years, is reproduced from KUKLA and GAVIN (1978). An abrupt increase of about 5×10^6 km^2, which amounts to almost 14% of the coverage can be found from 1970 to 1972 (KUKLA and KUKLA, 1974). The 12-month mean of temperature deviations averaged over the Northern Hemisphere (climatic noise of about 0.08°C) and that averaged zonally along 60°N (climatic noise of about 0.2°C) are also given. Relationship between the temperature fields and the coverage of snow and ice is not necessarily evident. No appreciable increase of snow- and ice-coverage is noticed in the period of 1968/1969 when a noticeable lowering of the temperature is detected. However, coldness is seen from 1970 to the first half of 1972 corresponding to the increase of snow- and ice-coverage, with some time delay of snow- and ice-coverage. Similar results for 24-month mean of sea ice extent are reported by WALSH and JOHNSON (1978). Some detailed examination is required about the fact that the increase of snow- and ice-coverage causes no detectable lowering of the temperature averaged over the Northern Hemisphere and the zonal mean along 60°N.

The period of the present data analysis is 27 years, which is too short to be utilized for examination of the effects of climate-controlling factors such as the atmospheric CO_2. Going back to the last quarter of the 19th century, the present



Figs. 5a, b. *The annual mean of Wolf number of sunspot and the 5-year running mean of the surface air temperature anomaly averaged over latitude belts of 30° lat. width. The 68% confidence interval of error in spatial averaging is shown with shading.*

author and his collaborator (YAMAMOTO and HOSHIAI, 1980) have analyzed the Northern Hemisphere mean temperature of the past 100 years. Much sparseness of the data network in the last century causes large error in spatial averaging. In the latter analysis, the error of annual mean air temperature averaged over the Arctic (90°N–60°N) is about ±0.25°C and nearly twice that of our former analysis of 27-years data (about ±0.13°C). However, these results may probably be feasible for some discussions in spite of large errors. The 5-year mean of the air temperature averaged over 90°N–60°N is given for the past 100 years in the bottom panel of Fig. 5a. The error in spatial averaging is about ±0.11°C and shown with shading, and the climatic noise in time averaging is also about ±0.11°C (YAMAMOTO *et al.*, 1981).

Numerical experiments by several scientists predict that doubling of the atmospheric CO_2 may cause an increase of the global mean surface air temperature by 1–3°C (*e.g.*, MANABE and STOUFFER, 1980). Their results show unanimously that the warming is greatest in the lowest layer of high latitude. Therefore, it is very interesting to examine long-term trends of the temperature in the Arctic. According to RAMANATHAN *et al.* (1979), when the atmospheric CO_2 increases to 1.33 times of the present concentration, a warming may appear by about 3°C at 85°N and by about 2°C at 65°N, respectively. Increase of the atmospheric CO_2 was about 25 ppm or about 8% from 1940 to 1975 (KELLOGG, 1977). It is not unreasonable to interpret that the numerical experiment by RAMANATHAN *et al.* (1979) would predict a warming in the Arctic of 0.5°C at least during the recent 35 years. This warming cannot be detected in the temperature change given in Fig. 5a, even if the error and noise of the estimated temperature and impacts of large volcanic eruptions are taken into account. Similar results are given for the zonal mean temperature of 60°N by MADDEN and TAMANATHAN (1980). Whether this undetectability of predicted warming would be described to the ocean thermal inertia by the other processes is one of the most important problems of climatic changes.

It is unquestionable that the solar radiation plays a governing role in the earth's climate and that the climate might change if the solar constant would vary. Numerical experiments by WETHERALD and MANABE (1975) show that a 2% increase of the solar constant may cause an increase of about 3°C of the global mean surface temperature, and increase of about 8°C of the zonal mean temperature at 80°N. No accurate measurements of the solar constant had been made until 1980 (STOW *et al.*, 1980). Relationship of the sunspot number to the climatic elements has been investigated by a number of scientists (HERMAN and GOLDBERG, 1978). Correspondence of time-change of the air temperature to that of the sunspot number had been investigated by KÖPPEN (1914) and others, who showed a negative correlation between them. Using the temperature data after 1920, TROUP (1962) indicated occurrence of a reversal of the correlation about 1920. It is meaningful to reexamine Troup's findings with the use of the spatial averaged temperature, taking account of the reliability. The 5-year mean temperature averaged over 3 latitude belts is given in Figs. 5a and 5b, together with Wolf number of sunspot. For these temperature changes, the confidence interval of the error in spatial averaging is shown with shading. The value of noise level in time averaging is about 0.11°C for 90°N–60°N, 0.06°C for 60°N–30°N and 0.02°C for 30°N–0°, respectively. Although the error and noise diminish the significance, Troup's findings are seen more clearly in the mid-latitude temperature than in the high latitude one. Referring to the numerical experiment by WETHERALD and MANABE (1975), this fact implies that there is no simple relationship between time-change of the solar constant and that of the sunspot number.

5. Concluding Remarks

The temperature field of the Arctic may probably be one of the most sensitive indicators of climatic changes. Therefore, the research of the arctic temperature is one of the most important tasks to interpret or predict a climatic change. However, deficiency of the routine meteorological observations makes it difficult to analyze reliably the arctic temperature field. In the present work, an optimum interpolation technique is applied to the network of monthly mean surface air temperature in the circumference of the Arctic Ocean. The results are compared with analysis results by WALSH (1977) who utilized the drifting ice station data. Both analyses agree fairly well, although some underestimations by the present work are noticed. This underestimation should be improved by normalization of weighting factors in optimum interpolation. It is preliminarily examined whether the change of the arctic temperature field would definitely relate with changes of climate-controlling factors such as the atmospheric CO_2. For definite conclusions, further research is required.

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